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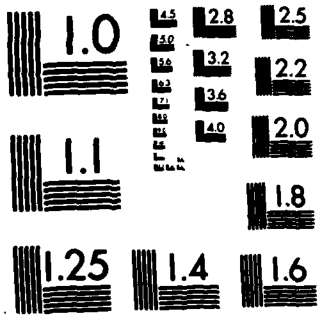

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Part-task trainers offer potential cost savings in flight training programs, in that relatively inexpensive devices might be used to train critical sub-skills prior to more comprehensive training in a simulator or in the criterion vehicle. Part-task methods are currently employed in many training programs with apparent success. However, there is no comprehensive statement of principles to guide users towards the best procedures or to help them maximize the effectiveness of procedures already being used. A review of the part-task training literature was undertaken to integrate the existing empirical data.

The review was intended to identify the more promising principles and procedures for part-task training, and to provide a coherent guide to future research.

Part-task training was defined as practice on some set of components of the whole task as a prelude to performance of the whole task. Part-task procedures are intended to improve learning efficiency and to reduce costs. Our review focused on the instruction of tracking skills for manual control. Transfer of training was emphasized and crucial features of the methodology and of means of assessing transfer were discussed. The part-task procedures of segmentation, fractionation and simplification were explained, and procedures for reintegrating parts into the whole task were summarized.

The segmentation procedure of backward chaining proved to be the most effective of the part-task methods. All available data on backward chaining show it to be superior to whole-task training. It was not possible to ascertain whether this is a general benefit of segmentation or whether backward chaining offers a unique advantage. We recommend further research on backward chaining to identify features that contribute to the power of this technique. In addition, other reintegration sequences for segmentation methods should be tested.

The fractionation methods were generally less effective than whole-task training and were never shown to be more effective. However, differential transfer was usually positive, so that relatively inexpensive part trainers that employ fractionation methods might be cost effective. There appears to be some potential for fractionation methods to be more effective, but lack of sufficient information about how perceptual-motor skills develop would seem to be forestalling progress. Consequently, more basic research should be undertaken to identify how perceptual-motor skills develop and how people organize elements of multidimensional tracking tasks. Once a body of knowledge is accumulated about how these skills develop, a more rational determination of how to make fractionation techniques more effective can be made.

Simplification techniques resulted in positive transfer, but were generally not superior to whole-task training. Thus, simplification techniques could be useful if the part training was relatively inexpensive. A small number of simplification experiments showed an advantage for part- over whole-task training. Specifically, manipulations of the ratio of pursuit to compensatory components in a display, augmented feedback, and rate and lag variations occasionally led to differential transfer of more than 100%. However, these manipulations did not provide consistent data, and further research is needed to determine the circumstances under which they can be effective.

Part-task training has considerable potential to reduce training costs. Almost any part-task method would seem to have some training value, particularly with inexperienced or low aptitude subjects and with difficult tasks. However, many procedures are not as effective as their whole-task counterparts, and care is needed to ensure that these procedures are employed in a cost-effective manner. A small number of other part-task procedures were more effective than whole-task procedures, and could probably be less costly. Such training techniques are particularly appealing. We suggested several lines of research that are needed to develop them.

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SECTION I

INTRODUCTION

Part-task training is defined as practice on some set of components of a whole task as a prelude to practice of or performance of the whole task. The rationale for part-task training is that whole-task performance will be improved by practice on task components. Part-task learning is well established as a basic principle underlying education. In mathematics, for example, operations such as addition, subtraction and multiplication are learned before algebra. These operations, together with special features, are essential components of the whole task of algebra.

The aims of part-task training are to reduce costs and to improve learning efficiency (Adams, 1960; Wheaton, Rose, Fingerman, Korotkin and Holding, 1976). These goals of economy might be achieved if part-task methods permitted worthwhile learning to occur in devices that were less expensive than the criterion device. Learning would not need to be as efficient or as fast if costs of using the part-task device were sufficiently less than those of using the criterion device. Faster learning is, however, a potential advantage for part-task training and, in the best of both worlds, a less expensive device might promote faster learning.

For many skills, part-task methods seem to be essential. Particularly difficult or complex skills such as advanced mathematics require years of instruction with a progressively difficult series of lessons. Presumably, no mathematics instructor would seriously consider teaching advanced problems to a beginning student. Such an approach would almost certainly destroy the motivation of even the most dedicated pupil. In addition, instructional tasks may have to lie within or near a trainee's current range of abilities for any learning to occur (Gaines, 1967; Wheaton, et al., 1976).

At an applied level, attempts to justify part-task procedures have been minimal, and evaluation has been limited to a small number of studies. There has been no comprehensive attempt to justify the methods that have been used to partition tasks or to reintegrate the parts during learning. Application of procedures is usually left to the judgment of individual

instructors. In general, it is unknown whether any specific part-task procedure is more efficient than the comparable whole-task procedure. Precedence and faith would seem to play a large part in the use of part-task methods.

Basic research has tended to weigh against part-task training. For example, Adams (1960) has noted that results favor whole over part training by two to one. However, reviews of the experimental work have suggested trends that seem important for effective application of part-task procedures. Adams (1960), Holding (1965), and Wheaton, et al. (1976), have noted that part-task training appears to be more effective with difficult tasks. Schendel, Shields and Katz (1978) have further observed that a difficult task should be partitioned into relatively independent components. Part-task training also appears to be more effective for low aptitude or inexperienced students (Schendel, et al., 1978).

The aims of this review are to reexamine these issues and to establish a conceptual structure to guide research in this area. Issues pertaining to tracking in manual control will be emphasized. Key concepts will be explicated, and a rationale for what has been done, and what should be done, will be developed. In particular, we will attempt to point to potentially productive areas for research, and to identify effective methods of partitioning the whole task and of reintegrating the parts during learning. Research areas that show little promise will also be noted.

SECTION II

RESEARCH METHODOLOGY

Tracking is a perceptual motor activity in which an operator is required to match the output of a manually controlled system to a continuously displayed reference signal. Some studies that might seem relevant will not be reviewed, specifically because they do not directly address issues of concern to instruction of tracking and manual control. In particular, the part-task training literature on verbal skills will not be considered. Perceptual and simple perceptual-motor skills will be considered only in relation to the insight that might be gained for further understanding of tracking skills. We refer occasionally to the techniques of Adaptive Training and Perceptual Predifferentiation because they too are concerned with enhancing transfer by first teaching selected components of the whole task (Wheaton, et al. 1976).

We concentrate on studies that use a Transfer-of-Training (TOT) paradigm to test part-task procedures. As a minimum, the TOT design includes experimental groups that learn the part and then transfer to a criterion or whole task. It also has a control group that learns the whole task during early trials, and continues with the whole task in the training session. Non-transfer experiments will be considered only if they suggest principles or techniques that could be tested in a TOT experiment.

This emphasis is justified on the basis of substantial data. There have been occasional attempts to infer the effectiveness of part-task training without a transfer phase (e.g., Munro, Fehling, Blais, and Towne, 1981). However, performance differences during training do not imply differential learning in relation to a specific criterion task. For example, comparisons of spaced and massed practice or of various training speeds can show substantial performance differences in training that do not remain after transfer to a criterion schedule (Reynolds and Bilodeau, 1952; Ammons, Ammons, and Morgan, 1956). Even where differences between training conditions are carried over to the transfer test they can be much smaller (Levine, 1953) or even reversed (Dashiell, 1924).

As any of these trends are possible in part-task training research, only a TOT design can substantiate the effectiveness of any specific technique.

Further concerns are that the experimental groups have equivalent practice on their designated part task and that the control groups have equivalent practice plus an appropriate testing period on the whole task. This test period for the control group is often referred to as the control group's transfer phase (e.g., Naylor and Briggs, 1963), even though the control group does not transfer to a different task. In this review it will be referred to as the control group's test phase.

Some TOT designs permit training to criterion. In part-task research this would generally mean that amount of training would not be equal for different experimental conditions, with those subjects who learn with the easiest part task having the least. Thus, the experimental effects would be confounded with amount of training so that equal transfer performances or transfer differences in favor of the longest trained group would be impossible to interpret. Only with the case in which the groups with least training show better transfer would there be any clear evidence that the training manipulations are differentially effective for transfer. Note, however, that there is no objection to a design in which transfer is continued to a performance criterion.

In summary, the appropriate TOT design will have two or more groups including at least one control group that is trained and tested on the whole task. Each group will be trained for a predetermined period in one and only one condition. Training periods will be equivalent across groups, although the balanced schedule of training periods employed in an incremental transfer design (Povenmire and Roscoe, 1973; Bickley, 1980) is acceptable and can provide important supplementary information. Control subjects remain on a criterion training condition throughout the experiment. They undertake a training and testing schedule that parallels the training and transfer schedules used for the experimental training conditions.

This type of design permits estimates of transfer and of differential transfer. Transfer reflects the effects of prior experience of a specific type on performance of the criterion task. The transfer performance of an experimental group is compared with the control group's performance during training. Differential transfer estimates the relative effects of equal amounts of experience with experimental and control conditions. The experimental group's transfer performance is compared with the control group's performance in the test phase. Both transfer and differential transfer provide useful information for basic and applied research.

Formulae for transfer are discussed in Roscoe and Williges (1980). Transfer can be positive or negative, but it cannot be greater than 100%. Differential transfer, which is occasionally reported as transfer (e.g., Briggs and Naylor, 1962), can have a value of more than 100%. Such a value indicates that training with the experimental condition is more efficient than is training with the control condition for later performance of the criterion task. A positive differential transfer value of less than 100% indicates that experimental training condition is less efficient but that it does teach some skills that are useful for performing the criterion task. This latter type of finding would lead to cost-effective application only if the training on the experimental condition is sufficiently less expensive than training on the control condition.

SECTION III

DEFINITIONS AND CONCEPTS

Segmentation, fractionation and simplification are the three types of part-task manipulations that have been identified in the psychological literature. Segmentation is a procedure that partitions on temporal or spatial dimensions. Many tasks can be considered as a series of subtasks that have identifiable end points. Subtasks can be practiced either in isolation or in small groups and then recombined into the whole task. An example is the backward chaining procedure of Bailey, Hughes, and Jones (1980) in which the final segment of a bombing task was practiced first and prior segments were successively added during training. Bailey *et al.* (1980), used spatial segmentation for this task, but temporal segmentation would be possible for some tasks.

Fractionation is a part-task manipulation that can be appropriate for a whole task in which two or more subtasks are executed simultaneously. An example is straight-and-level flight where both pitch and roll must be controlled. A part-task procedure might permit independent practice on pitch and roll before they were combined into the whole task.

Simplification is a procedure in which a difficult task is made easier by adjusting one or more characteristics of the task. Reduction in the control-display lag of a tracking system can reduce difficulty (Levine, 1953) and could form the basis of a simplification procedure for part-task training. Lag can also form the basis of an adaptive training manipulation (Norman, Lowes and Matheny, 1972; Norman, 1973) and, in general, many of the task dimensions that have been manipulated in adaptive training (Lintern and Gopher, 1980) could be used for simplification in part-task training.

A central feature of any part-training method is the schedule that is used to reintegrate the parts. Three such schedules have been identified for the fractionation method (Naylor, 1962). Pure-part training refers to a procedure in which parts are practiced in isolation before they are combined into the whole task. In repetitive-part training one part is practiced in isolation and then another is added. After more practice a third part is added and this process is continued

until the whole task is being practiced. Progressive-part training is similar except that each new part is practiced in isolation before it is added to any parts that have already been practiced.

These three schedules could also be applied to the segmentation method of part training and other variations on these reintegration schedules are possible. With simplification the size of the step increase in difficulty could be varied. Thus, transition from part to whole training might be accomplished in one large step or in a series of smaller steps.

SECTION IV

SEGMENTATION

BACKGROUND

The most obvious advantage of segmentation is that difficult parts of a task can be practiced intensively without spending time on parts that are easier to learn or already are well learned. Aircraft landing instruction offers an example in that the final approach, flare and touchdown are the segments that are most difficult to learn. In normal flight training a considerable amount of time is consumed during takeoff and pattern flight. A part-task trainer would permit concentrated practice on the final part of the task, thereby increasing the efficiency of training.

EMPIRICAL RESULTS

Bailey, Hughes and Jones (1980) compared the backward chaining technique to whole-task practice of a 30-degree dive bomb maneuver. These investigators segmented the task based upon the commonly used subelements of final approach, roll-in, base leg and downwind leg. Subjects in the backward chaining group practiced the terminal segment first. Preceding segments were added successively until practice on the whole task was accomplished. A control group practiced the whole task throughout training. Upon transfer to the whole task the backward chaining group exhibited significantly fewer errors than did the whole-practice group. Further analysis revealed that in the time taken for seven of ten subjects in the backward training group to reach criterion, only three of ten subjects in the whole practice reached criterion.

Westra (1982) reported an experiment in which subjects practiced carrier landings in a simulator with a wide-angle visual system. The whole task was a circling approach to landing. A pure-part procedure was used to teach some subjects a straight-in approach before they were tested on the whole

task. In this experiment, control time in training was equated for the two groups by extending the distance of the approach beyond what was essential to learn the task.

The part-task procedure resulted in better final-approach lineup performance during the training phase, presumbably because it allowed subjects more time to establish themselves on the extended centerline of the landing deck. In testing on the whole task (i.e., circling approaches to landing) lineup performance was again superior for the group trained on straight-in approaches, even though the subjects now had to cope with the new difficulty of establishing lineup when they were much closer to the landing deck. The difference between the groups was substantial and continued through the testing phase. There was no noticeable decrement at the transition from straight-in to circling approaches.

Wightman (1983) taught straight-in carrier approaches with a repetitive part technique. The whole task was a straight-in approach to landing from 6000 feet behind the simulated landing deck. Part-task subjects started with approaches from 2000 feet and transitioned to approaches from 4000 feet when they had completed one-third of the training phase. The final third of the training phase involved practice on the whole task. The control subjects were allowed the same number of training trials to practice the whole task and therefore practiced the final 2000 feet of the task for an equal amount of time. However, they did have some advantage over the part-task subjects in that they had 50% more total practice time with glideslope tracking. Nevertheless, the part-task trained subjects had lower RMS error scores for glideslope tracking in the testing phase.

There was a significant interaction between training conditions and subject aptitude. The performance of both high and low aptitude whole-task subjects suffered in comparison to those of the part-task subjects. High-aptitude subjects overcame this disadvantage before the end of the testing phase whereas the disadvantage for low-aptitude subjects remained throughout the testing phase. Thus, part-task training appeared to be more critical for the low aptitude subjects.

Sheppard (1984) also used straight-in simulated carrier approaches as his whole task. His part-task procedure was to freeze the ground position so that subjects could learn glideslope control. They were transferred to the whole task after training. This technique was not as effective as that tested by Wightman (1983). Sheppard's part-task subjects had higher RMS glideslope error scores than his whole-task subjects in the testing phase, although transfer was positive.

DISCUSSION

Segmentation appears to be a promising technique. Three of the four experiments reviewed show an advantage for part training. It is possibly significant that the three most favorable results emerged from a backward chaining technique.

As noted earlier, the most obvious advantage of segmentation is that it permits intensive practice on the most difficult portion of the task and could permit more practice on the difficult portion than would whole-task training, given equal time for the two methods. It is well known that amount of practice impacts learning, so that more extended practice on a difficult segment should permit that segment to be learned more effectively. Note, however, that Wightman (1983) has shown an advantage for backward chaining even though experience with the final and critical segment of the task was equivalent for both part and whole groups, and was greater overall for the whole group. Thus, practice time is not the only element that enhances the effectiveness of backward chaining. Furthermore, mere isolation of a critical element for extended practice does not seem to be a particularly powerful technique (Sheppard, 1984).

The nature of the facilitating effect of backward chaining has not been determined, but some hypotheses can be derived from the literature on perceptual-motor learning. The concepts of interference due to activity before knowledge of results (KR), interference due to activity immediately after KR, habit formation, error free performance, and stimulus-response consistency are considered in the following paragraphs.

In terminal tasks such as landing an airplane, gunnery or bombing, earlier segments may not be learned quickly because they are separated from the potent feedback of the final result. Bilodeau (1956) and Boulter (1964) have shown that activity between action and KR interferes with the progress of learning, possibly because it obscures the association between action and errors. Thus, lengthy perceptual-motor tasks may be naturally acquired in a backward progression where later task segments, once well learned, become the source of information feedback for earlier segments. Later segments of an extended task may interfere with learning of earlier segments by separating them from KR. This process could permit the development of inefficient habits in the early segments which, if difficult to correct, would impede whole-task learning.

Post KR processing may also be important (Schendel and Newell, 1976). The post KR period apparently permits the learner to relate error information to his earlier actions. Other activity, such as prompt repetition of earlier task segments, may interfere with this process whereas immediate

performance of the final segment could conceivably facilitate it. While the evidence for the interfering effects of activity before and after information feedback are sparse, especially for tracking in manual control, these concepts could provide useful hypotheses.

Other hypotheses can be generated from the suggestion that learning of the final segment is more effective with backward chaining because students do not have to cope with the ambiguities resulting from errors accumulated in prior segments. Consistency in stimulus-response relationships is known to be important in learning (Gordon, 1959; Shiffrin and Schneider, 1977). Thus, whole task learning may be slowed because incorrect responses in different segments of the task result in similar errors. If only the final segment is practiced, the student should more easily be able to associate the error feedback with the incorrect response.

Alternatively, part-trained subjects may learn more quickly simply because they experience a correct performance more frequently. Schneider (1982) has observed that learning proceeds more rapidly with the execution of errorless performances. Correct habits might be strengthened more quickly, or the student might learn to recognize the correct behavior more quickly. Note, however, that the notion that error-free training would speed learning was not supported in an experiment on carrier landing training (Hughes, Lintern, Wightman, Brooks, and Singleton, 1982).

The treatment by subject interaction found in Wightman's (1983) data is also noteworthy. While high-aptitude subjects could quickly overcome the disadvantage of whole training, low-aptitude subjects could not. This appears to be consistent with Holding's (1965) contention that part methods are more useful with difficult tasks. It is possible that part methods may be unnecessary or even counterproductive for very able subjects or with easy tasks.

Whether segmentation is more efficient than whole-task training probably depends to some extent on the nature of the task, as well as its overall difficulty and the aptitude of the students. The previous comments suggest that tasks that have considerable variations in difficulty between segments, or that encourage development of inefficient strategies, are potential candidates for segmentation. Backward chaining has been particularly successful in tests of segmentation and it remains to be seen whether this sequence offers some unique advantage, or whether principles that allow for more flexible sequencing of the parts can be uncovered.

SECTION V

FRACTIONATION

BACKGROUND

Fractionation has been accomplished in experimental work by partitioning tracking tasks into their control dimensions, their perceptual and motor components, or their continuous and procedural components. Concerns for fractionation are those of the difficulty of each of the components (subtask difficulty) and the need for timesharing between the components (subtask interaction). In some tasks the timesharing element may be the only source of difficulty, so that fractionation for training purposes could be counterproductive. In other tasks many or possibly all of the parts may be too easy to warrant isolated attention.

Naylor and Briggs (1963) have shown the relevance of subtask interaction and subtask difficulty with a prediction task. Their results demonstrated that progressive part training for high subtask difficulty combined with low subtask interaction was superior to whole training. In contrast, progressive part-training with high subtask difficulty and high subtask interaction, low subtask difficulty and low subtask interaction, and low subtask difficulty and high subtask interaction were poorer than for whole learning. While the relevance of this experiment to tracking in manual control is questionable, the results do show a pattern that might be anticipated in tracking research.

EMPIRICAL RESULTS

Briggs and Brogden (1954) tested pure-part training with a two-dimensional lever-positioning task. Part groups practiced single dimensions of the task, with some groups practicing only one dimension and others alternating between both. Differential transfer was positive for all part-trained groups, but was less than 100%, possibly because the parts were easy to perform on their own, and the movements required were different from any used in the whole task.

Briggs and Waters (1958) reported two experiments in which subjects practiced pitch and roll tracking in a flight simulator. The second is more relevant to simplification, and is discussed later. In the first experiment, subjects practiced pitch and roll tracking in isolation before they practiced them together. Interaction between pitch and roll was manipulated, with errors in roll adding to pitch error in conditions of high subtask interaction. Differential transfer was positive but never greater than 100%. High subtask interaction was associated with lower differential transfer.

Briggs and Naylor (1962) used a three-dimensional compensatory tracking task to test pure-part and progressive-part procedures (a simplification procedure that was also tested is discussed later). The subtasks were derived by separating the whole task into three single-dimension tracking tasks. Total tracking time was constant for all subjects in this experiment. Differential transfer was less than 100% for both experimental training conditions. Two levels of difficulty were established for the criterion tasks. Differential transfer was higher for the more difficult task. Progressive-part training was better than pure-part training and, for the high-difficulty criterion task, was as good as whole-task training.

Stammers (1980) examined pure-part training with a two-dimensional tracking test. There was a high degree of interaction between the dimensions in that the target's position in relation to one axis could frequently be predicted from its prior position on the other axis. Whole-task difficulty at two levels was obtained by adjusting control-display compatibility. Differential transfer was positive but less than 100% for both high- and low-difficulty tasks.

In the experiments by Briggs and Brogden (1951), Briggs and Waters (1958), Briggs and Naylor (1962), and Stammers (1980), part- and whole-trained subjects were given an equivalent amount of training. Thus, part-trained subjects had less practice with separate dimensions than did the whole-trained subjects. It could be argued that part-trained subjects should be given the same amount of training on each dimension as control subjects have on the whole task. Stammers (1980) used two training periods in his experiment, so that it is possible to make this comparison from figures contained in his report. Even with this type of comparison, part training was no better than whole training.

Adams (1960) taught experienced pilots a complex bomb delivery task by partitioning the whole task into continuous tracking elements (controlling the simulated aircraft) and discrete motor responses (setting switches in the cockpit). Control subjects were given 16 training trials on the whole task and experimental subjects were given 16 training trials on each

of the parts. There were no differences between groups in testing on the whole task except that the part-trained groups did not perform the discrete responses well on their first transfer trial. Adams concluded that this kind of part training can be of value when it is less costly than whole training.

Adams and Hufford (1961) tested the effectiveness of visual pretraining for teaching landings in an aircraft simulator with a visual display. Their experimental subjects viewed a series of preprogrammed landings and were then tested on their ability to land the simulator. Control subjects were not permitted to view the preprogrammed approaches. There was no statistically significant difference between the landing performances of control and experimental groups. Thus, passive viewing of landings appeared to teach nothing of value for later landing trials.

Although this perceptual manipulation was ineffective, the approach used by Adams and Hufford (1961) is of interest because it constituted a deliberate attempt to teach a crucial perceptual skill that is difficult to learn with normal instructional procedures. The attempt to pretrain perceptual skills has a long history, and the empirical literature has been reviewed by Arnoult (1957) and Gibson (1953, 1969). However, only a small portion of the experiments they reviewed used a transfer paradigm, and an even smaller portion tested transfer to a motor task.

While these reviews indicate that perceptual skills improve during training, there remains some doubt about how effectively they transfer to a new situation. For example, Gagne and his associates examined pure-part training with a reaction-time apparatus. Subjects were required to activate one of four switches based on a color and position code that was signalled by activating one of four lights. The crucial problem in this task was to learn the correct association between the color-position codes and their respective switches. Gagne and Foster (1949) and Gagne, Baker, and Foster (1950) pretrained experimental subjects on either the position or the color code. This pretraining helped transfer but was not more effective than equal practice on the whole task.

DISCUSSION

None of the experiments that used tracking tasks showed an advantage for part-task learning over whole-task learning. Some of the conditions tested did demonstrate positive transfer to the criterion task, and could be useful if the part training could be accomplished relatively cheaply.

Subtask interaction appears to be an important variable. Whole tasks having high subtask interaction are poor candidates for part training. Task difficulty also had some impact on the effectiveness of part-task training and, as noted earlier, may generally influence the efficiency of part-task training. In both experiments in which this was manipulated part training was more effective with the difficult task. Although the data reviewed here are discouraging for the application of fractionation methods, the theoretically most efficient combination of low subtask interaction and high task difficulty has not been tested in a manual control context.

Other methods of partitioning manual control tasks may be possible. The approach that has been taken appears simplistic and it may be more profitable to analyze the nature of the task and attempt to establish a part-training schedule that is consistent with that analysis. For example, Briggs (1961) has noted that there is relatively more use made of higher-order error information as tracking skills are acquired. In effect, beginners respond predominantly to displacement error while experienced trackers respond to velocity and acceleration errors.

This observation suggests a possible training manipulation. It may be advantageous to follow the natural order with a schedule that teaches responses first to displacement, then to rate, and then to acceleration information. Alternatively, it might be more efficient to concentrate on the skills that dominate skilled behavior, so that early instruction in responding to acceleration or rate information may speed acquisition of the whole skill.

A further class of manipulations is suggested by the work of Jaeger, Argawal, and Gottlieb (1980) who have argued that a tracking skill develops through identifiable stages. The directional relationships are learned first, followed by timing, and then by the spatial relationships. Their data and those of Trumbo, Noble, Cross, and Ulrich (1965) and of Noble, Trumbo, Ulrich and Cross (1966), all from one-dimensional tracking studies, support this view. The data from a three-dimensional tracking study by Lewis, McAllister, and Bechtold (1953) has shown coordination to be a late developing factor, while an experiment by Pew (1966) that was specifically designed to study the acquisition of temporal patterning in tracking, has shown temporal organization to be a significant feature of skilled performance.

So little is known about perceptual motor skill development that it is not clear that these data are consistent with a larger overall pattern. Nevertheless, they suggest the possibility that skill development proceeds through a hierarchy of stages, and that these stages could be identified. A working

hypothesis to emerge from these data is that directional relationships, timing, amplitude and coordination tend to develop in sequence. Organization, either spatial or temporal, might develop last as the skill becomes automatic.

Identification of stages of learning in this manner may suggest how it is possible to develop special part-task strategies that impact each of these processes. However, even this simple conceptualization does not have a straightforward application. As previously noted in the discussion of progressive development of responses to displacement, rate and acceleration information, a first supposition is that stages should be taught in their sequence of natural development. However, it is also possible that skill acquisition could be speeded by focusing on stages of development before their natural occurrence, possibly forcing the student to progress more rapidly.

A general conclusion that might be drawn from the perceptual pre-differentiation literature is that perceptual pretraining could be useful if the perceptual component is critical, and if the pretraining can be conducted relatively inexpensively. It also appears that subjects need to actively search for distinguishing perceptual cues or to make some decision about the visual stimuli during pretraining (Arnoult, 1957). This may explain the ineffectiveness of the passive viewing procedure used by Adams and Hufford (1961).

One particularly intriguing result is provided by Schneider (1982). In this research, subjects were taught visual-spatial skills that are a part of a military air traffic controller's task to guide two aircraft into an air-to-air refueling position from several miles apart. The task requires about twenty minutes in real time, but Schneider (1982) used a schematic simulation that completed the problem in approximately twenty seconds. Subjects were given hundreds of trials with the spatial task in less time than real trainees can be given a normal complement of forty trials. The performances of the experimental subjects appeared to become far better on the spatial component of this task than those of real controllers.

Although this experiment did not include an appropriate test of transfer, it does suggest what might be accomplished by partitioning a task that is heavily dependent on a perceptual skill. Experimental subjects were actively involved in the solution of a problem in each trial, and the trial sequence was speeded so that its events would not tax the limits of short-term memory. Further development of this type of strategy would seem to be warranted.

SECTION VI

SIMPLIFICATION

BACKGROUND

The notion of an optimum level of difficulty for learning has been emphasized in some part-task research, and has formed the basis of the Adaptive Training research (Kelley, 1969). While a training task that is easier than the criterion task is usually proposed, more difficult training tasks have been considered (Ammons, et al., 1954; Holding, 1965). Although difficult-to-easy transfer is not relevant in a strict sense to part-task simplification, any observed advantage for that type of manipulation would seem to provide evidence against a simplification procedure. Thus, the difficult-to-easy transfer results will be noted when they seem to bear on the issue of simplification.

Discussions of transfer between easy and difficult tasks can become muddled. For example, some data show greater transfer from difficult-to-easy tasks than from easy-to-difficult tasks (Day, 1956). As Holding (1965) notes, this does not necessarily mean that training should be conducted on the more difficult version of the task. It could still be better to use the criterion task for training. An easier or a more difficult training task is warranted only if relative transfer to the criterion task is greater than 100%, or if a cost index shows training on the experimental task to be more cost effective. Reviews by Day (1956) and Holding (1962) have failed to clarify this issue.

The most apparent advantage for simplification is with tasks that are too difficult to allow learning to progress or are so difficult that learning is slowed. Some skills learned with an easy version of a task might be applied in learning the more difficult version. House and Zeaman (1960) have, for example, shown that difficult pattern discriminations become easier to learn after practice with easier object discriminations. Similarly a tracking task could be so difficult that the student would be unable to maintain control for even a short period of time, thereby precluding or limiting the possibility of any meaningful practice on the task.

Gaines (1967) has argued that practice with an easier task could extend students' skills so that performance of the criterion task would no longer be beyond them. It is also possible that practice on an easy task establishes a high performance standard as a goal that can serve to motivate the student after transfer to a more difficult task (Holding, 1965). On the other hand, a more difficult version of the criterion task would force students to extend themselves. That may speed learning of skills that are useful for performance of the criterion task or may establish resistance to forgetting or stress.

Before reviewing the data to assess those arguments, some clarification of the use of the terms simplification and difficulty seems warranted. We recognize that their use to describe experimental manipulations is not entirely satisfactory. It would be more precise to specify the experimental manipulation. Any resulting change in difficulty would be reflected in performance measures. Holding (1965) has in fact stated that there is no such thing as difficulty. Nevertheless, the terms are used so frequently in the literature to be considered that it would be inconvenient to avoid them. However, it should be noted that difficulty can be adjusted with a variety of manipulations and it is unlikely that all would have similar effects on learning and transfer.

EMPIRICAL RESULTS

Briggs and Waters (1958), in the second of a pair of experiments (the first was discussed under the topic of fractionation), transferred subjects from both high- and low-component interaction in a two-dimensional (pitch and roll) tracking task to a criterion task with medium-component interaction. Differential transfer was positive for all conditions but less than 100%.

Briggs (1961) examined transfer to a second-order tracking task after practice on zero-order and second-order versions of that task. Again, the differential transfer was positive but less than 100%. Briggs and Naylor (1962), in a follow-up study, also adjusted system order in their training task and obtained similar results for both high- and low-difficulty criterion tasks.

Other data that are relevant to simplication in part-task training have been generated from transfer-of-training and adaptive training experiments. Manipulations of system order, system gain, system lag and forcing function have been popular. System stability and damping ratio have also been manipulated. Following a comprehensive review of these data, Lintern and

Gopher (1980) concluded that simplification along any of these dimensions does not enhance training efficiency.

Although we generally concur with this analysis, reexamination of those data indicate some advantage for transfer from medium- to high-difficulty tasks with a manipulation of rotation speed (Ammons, et al., 1954), and of control-display lag (Levine, 1954). In both of these experiments, subjects were trained on high-, medium- and low-difficulty tasks and were transferred to one of the same set of high-, medium- or low-difficulty tasks. Differential transfer from medium to high difficulty was greater than 100%, although transfer from low to medium, and low to high difficulty was not. In only one experiment has a differential advantage for transfer from a difficult to an easier task been claimed, that being in transfer from high- to medium-speed tracking (Williges and Baron, 1973).

Among this generally discouraging evidence, variation of the pursuit versus compensatory nature of a display has emerged as a manipulation that shows some promise. Pursuit displays are easier to track than are compensatory displays (Poulton, 1974). Gordon (1959) has shown that subjects who were trained with a pursuit display performed better on transfer to a compensatory display than did subjects who had equivalent training on the compensatory display. A compensatory tracking system might be simplified for training purposes by transformation into a pursuit system. Although Gordon's results were unambiguous, they must be balanced against those obtained by Briggs and Rockway (1966) which showed no differential advantage on a compensatory transfer task for groups of subjects trained with degrees of display pursuitedness ranging from zero (fully compensatory) to 100% (fully pursuit).

Although augmented-feedback research does not strictly fall in the domain of part-task training, it would seem remiss to neglect these data entirely. Lintern and Roscoe (1980) have reviewed laboratory and simulator studies of training with augmented feedback and have concluded that it can speed acquisition if students are not permitted to develop dependencies on the supplementary cuing. They suggested an adaptive withdrawal technique to avoid such dependencies. In a study conducted since that review, Lintern, Thomley, Nelson, and Roscoe (1984) have shown a strong effect of adaptive visual cuing on air-to-ground bombing instruction. Differential transfer in favor of augmented-feedback training was greater than 100%.

DISCUSSION

The principle of simplification is consistent with common practice in a variety of educational and instructional

environments. Nevertheless, it has been difficult to show that simplification procedures are more powerful than whole-task training. These procedures would generally be useful only if they were less expensive than whole-task procedures. However, it is possible that prior training on medium-difficulty tasks would show a differential advantage for later performance on a high-difficulty task, and manipulation of display pursuitedness could also enhance training effectiveness. In addition, augmented feedback may improve the instructional efficiency for some manual control tasks.

The possibility that simplification would be most effective only with a medium-difficulty training task and a high-difficulty criterion task seems to have escaped the attention of part-task researchers. Further tests that are aimed specifically at examining an hypothesis of this type may be productive.

The augmented-feedback and display-pursuitedness manipulations appear to provide a student with less ambiguous information about the effects of his control movements on the system he is controlling. This might be hypothesized as a general principle that warrants empirical study. Augmented feedback has an extensive literature, but only recently has it been taken from laboratory tasks to be applied to more practical manual control tasks. As yet, little is known about how to optimize its effectiveness for training.

The confusion about the usefulness of display pursuitedness should also be resolved. Data from only two experiments can be brought to bear on this issue, and they are not consistent. Lintern and Gopher (1980) have observed that Gordon (1959) used a spring-loaded control while Briggs and Rockway (1966) used a quasi-isotonic control. If transfer from pursuit to compensatory tasks depends on proprioceptive cues learned in the pursuit task, the system used by Briggs and Rockway would produce less transfer than the one used by Gordon. This hypothesis needs to be resolved as a prelude to investigation of display pursuitedness as a training variable.

SECTION VII

ADDITIONAL COMMENTS

Part-task training has recently been popularized in the form of video gaming. Extravagant claims have been made about the transfer of video game skills to control of complex and high performance vehicles. The flavor of these discussions suggests a return to the doctrine of formal discipline. This view contended that abilities such as reasoning, judgment and memory could be trained through the study of specific subjects such as mathematics and Latin. However, with video gaming, abilities such as timing, psychomotor coordination, and perceptual judgment are discussed. Players of video games are considered to develop those skills in a way that would help them control a high performance aircraft, to perform accurately with weapons, or to execute all manner of manual control tasks at high levels of skill.

Our review of part-task training has indicated that this is an overly optimistic expectation. There is solid evidence that specific part-task manipulations can speed learning, and we can expect that video game and microcomputer technology will play a large part in the application of these techniques. In addition, some of the software, or certain dimensions of some video games, may supplement our training procedures. Nevertheless, a comprehensive approach to part-task training must be based on careful analysis of criterion tasks and tailored development of hardware and software for specific tasks.

The area of embedded training is one in which computer technology may be productively allied with part-task training. Embedded training refers to the use of extra computational power in tactical systems for training purposes. This concept, previously referred to as "Operational Context Training" (Human Resources Research Organization, 1958), has had limited testing. However, the results have been encouraging (Germas and Baker, 1980) and other research has suggested the benefits of training in an operational environment (Holmgren, Hilligrass, Swezey, and Eakins, 1979). Embedded training could be particularly beneficial if it could exploit hardware that was already available in tactical or operational systems to permit part training in field or operational units.

A fundamental assumption of part-task training is that components of a task can be identified, and that improved skill on the components will help performance of the whole task. It is evident that proper partitioning of the task is crucial to the success of this technique. Nevertheless, there has been no attempt, in any of the studies reviewed here, to independently validate the partitioning procedures that have been used.

One promising validation technique is that of backward transfer, in which subjects are taught the whole task, and then tested on the parts that are postulated to be critical to performance of the whole task. Improved performance on the parts, as a result of whole-task training, would seem to validate the partitioning procedure. It seems noteworthy that a recent experiment of this (Salthouse and Prill, 1983) failed to show any significant improvement in part performance, following training on the whole task. This failure underlines the danger of relying on subjective procedures to partition the task.

Development of part-task methods has been and continues to be restricted by our limited understanding of how tracking skills are learned. The most pertinent issue is that of transfer between instructional and criterion tasks. Although transfer research has a long history, basic processes underlying transfer are poorly understood. There is no comprehensive model to adequately describe transfer relationships between tasks. Those that do exist (Holding, 1976; Wheaton et al., 1976) offer little guidance for specific manipulations that will transfer well.

In addition to identifying part-task manipulations that do enhance transfer, this review has sought to clarify the principles underlying transfer from part to whole tasks. Although this attempt had only limited success, it is clear that a programmatic approach to part-task training research is possible. Such a research program might uncover many useful principles, and might establish part-task training as an applied methodology.

SECTION VIII

CONCLUSIONS

Part-task trainers offer potential cost savings in flight training programs, in that relatively inexpensive devices might be used to train critical subskills prior to more comprehensive training in a simulator or in the criterion vehicle. Part-task methods are currently employed in many training programs with apparent success. However, there is no comprehensive statement of principles to guide users towards the best procedures or to help them maximize the effectiveness of procedures already being used. A review of the part-task training literature was undertaken to integrate the existing empirical data. The review was intended to identify the more promising principles and procedures for part-task training, and to provide a coherent guide to future research.

Part-task training was defined as practice on some set of components of the whole task as a prelude to performance of the whole task. Part-task procedures are intended to improve learning efficiency and to reduce costs. Our review focused on the instruction of tracking skills for manual control. Transfer of training was emphasized and crucial features of the methodology and of means of assessing transfer were discussed. The part-task procedures of segmentation, fractionation, and simplification were explained, and procedures for reintegrating parts into the whole task were summarized.

Segmentation is a procedure that partitions on the basis of spatial or temporal dimensions. An example is the backward chaining procedure in which the final segment of a task is practiced first and earlier segments are added progressively throughout training. Fractionation partitions a task on the basis of subtasks that are normally executed simultaneously. An example of fractionation is the partitioning of aircraft control during straight-and-level flight into the subtasks of pitch and roll control. Simplification is a procedure in which a difficult task is made easier by adjusting one or more characteristics of the task.

The segmentation procedure of backward chaining proved to be the most effective of the part-task methods. All available data on backward chaining show it to be superior to whole-task

training. It was not possible to ascertain whether this is a general benefit of segmentation or whether backward chaining offers a unique advantage. We recommend further research on backward chaining to identify features that contribute to the power of this technique. In addition, other reintegration sequences for segmentation methods should be tested.

The fractionation methods were generally less effective than whole-task training and were never shown to be more effective. However, differential transfer was usually positive, so that relatively inexpensive part trainers that employ fractionation methods might be cost effective. There appears to be some potential for fractionation methods to be more effective, but lack of sufficient information about how perceptual-motor skills develop would seem to be forestalling progress. Consequently, more basic research should be undertaken to identify how perceptual-motor skills develop and how people organize elements of multidimensional tracking tasks. Once a body of knowledge is accumulated about how these skills develop, a more rational determination of how to make fractionation techniques more effective can be made.

Simplification techniques resulted in positive transfer, but were generally not superior to whole-task training. Thus, simplification techniques could be useful if the part training was relatively inexpensive. A small number of simplification experiments showed an advantage for part- over whole-task training. Specifically, manipulations of the ratio of pursuit to compensatory components in a display, augmented feedback, and rate and lag variations occasionally led to differential transfer of more than 100%. However, these manipulations did not provide consistent data, and further research is needed to determine the circumstances under which they can be effective.

An additional concern was expressed about the limited knowledge in relation to principles and theory underlying transfer. One conclusion that might be drawn from this review is that the part-task research has often been superficial, and has generally appeared fragmented because it has not been tied to a comprehensive theory. In fact, there is no suitably powerful theory of transfer, and there seems to have been little progress towards developing one during the approximately thirty years of research that has been considered here. A programmatic approach to research and theory development for transfer, particularly in relation to teaching skills and manual control, could do much to advance the cause of part-task training.

In conclusion, part-task training has considerable potential to reduce training costs. Almost any part-task method would seem to have some training value, particularly with inexperienced or low aptitude subjects, and with difficult tasks. However, many procedures are not as effective as their whole-task counterparts, and care is needed to ensure that these

procedures are employed in a cost-effective manner. A small number of other part-task procedures were more effective than whole-task procedures, and could probably be less costly. Such training techniques are particularly appealing. We suggested several lines of research that are needed to develop them.

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